Planar Leaky-Wave Antennas Based on Microstrip Line and Substrate Integrated Waveguide (SIW)

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Abstract

Abstract: Recent advances of our researches on planar leaky-wave antennas are summarized. The planar leaky-wave antennas are fabricated on microstrip line and substrate integrated waveguide (SIW), which are low profile, low cost and easy to manufacture. They can inherently generate a narrow beam that scans with frequency. Researches were performed with special emphasis on the theoretical calculation and the excitation of the first higher mode in the microstrip leaky-wave antennas, and the endfire radiation and the circular polarization with the SIW leaky-wave antennas.

Key words: Leaky-wave antennas, microstrip antennas, SIW antennas, wavenumber.

Biography

Juhua Liu was born in Heyuan, Guangdong, China, in September, 1981. He received the B.S. and Ph.D. degrees from the Sun Yat-sen University, China, in 2004 and 2011, respectively.

From 2008 to 2009, he was a Visiting Scholar in the Department of Electrical and Computer Engineering, University of Houston, Houston, TX, USA.

From September 2011 to September 2012, he was a Senior Research Associate with the State Key Laboratory of Millimeter Waves, City University of Hong Kong, Hong Kong, China.

From 2012-2015, he was a Lecture in the Department of Electronics and Communication Engineering, Sun Yat-sen University, Guangzhou, China. Since 2015 he has been an Associate Professor in the same department.

His present research interests include leaky-wave antennas, microstrip antennas, substrate integrated waveguide antennas, antenna theory, and computational electromagnetics.

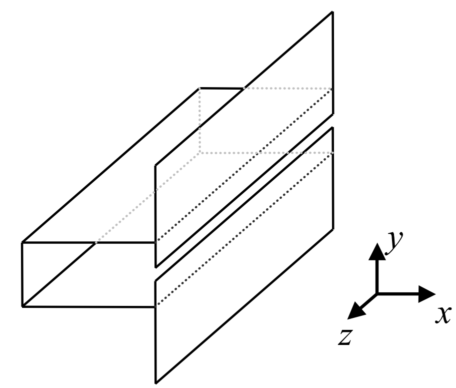
Outline

- 1. Introduction
- 2. Microstrip leaky-wave antennas
- 3. SIW leaky-wave antennas
- 4. Conclusion

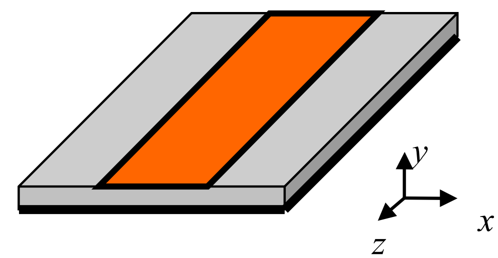
1. Introduction

History

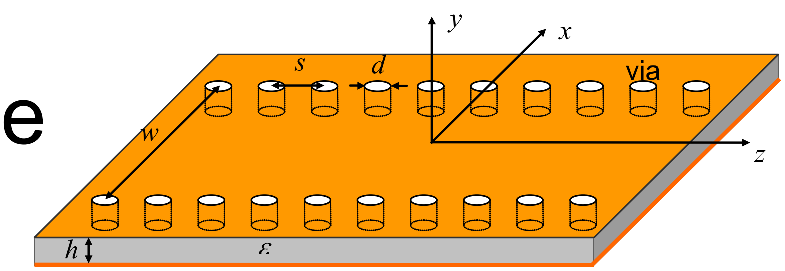
- In 1940, (Hansen) waveguide leaky-wave antenna



- 1981, (Menzel) microstrip leaky-wave antenna



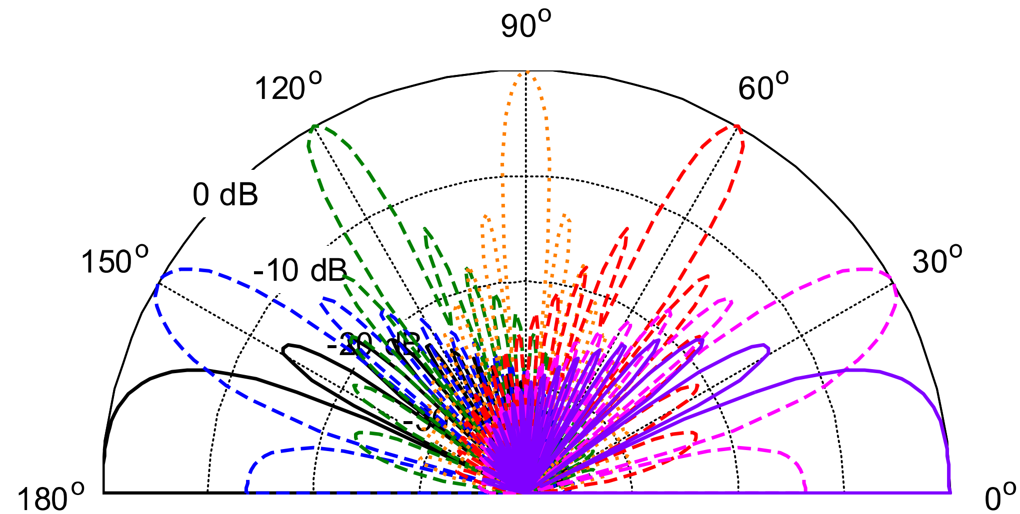
- This century, SIW leaky-wave antenna



1. Introduction

❖ Advantages

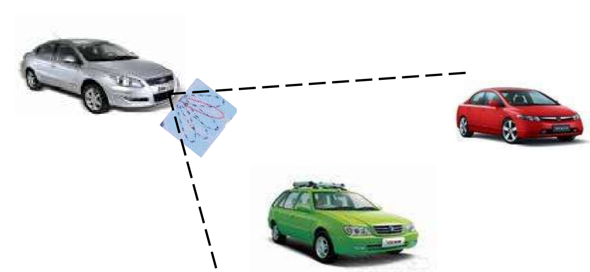
- Narrow beamwidth, high gain
- Beam scanning
- Simple structure
- Easy feeding



1. Introduction

Applications

- Collision-avoidance radar (e.g., vehicle), radar sensor
- Wireless location
- Military（target tracking in high-speed flight）
- Wireless communications

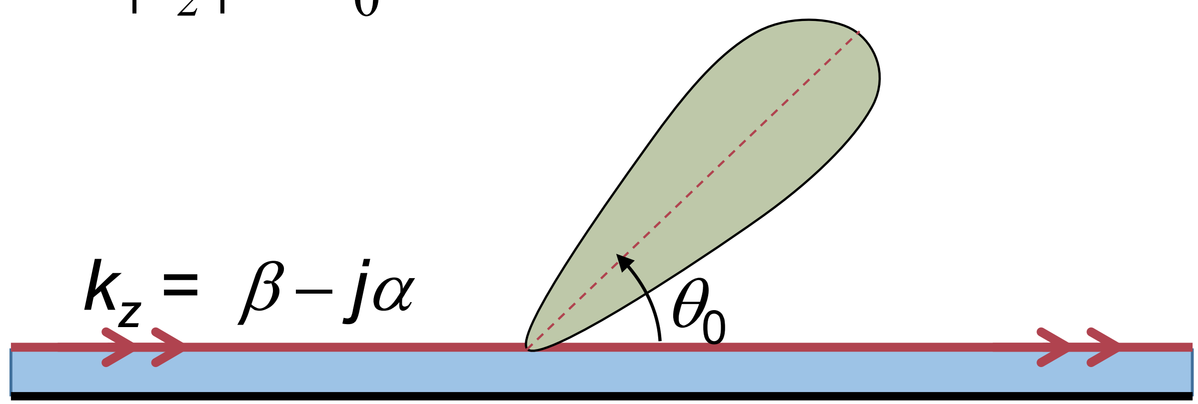


1. Introduction

❖ Key parameter: propagation wavenumber $k_z = \beta - j\alpha$

- Phase constant $\beta \rightarrow \theta_0$
- Attenuation constant $\alpha \rightarrow \Delta\theta$
- Region $|k_z| \leq k_0$

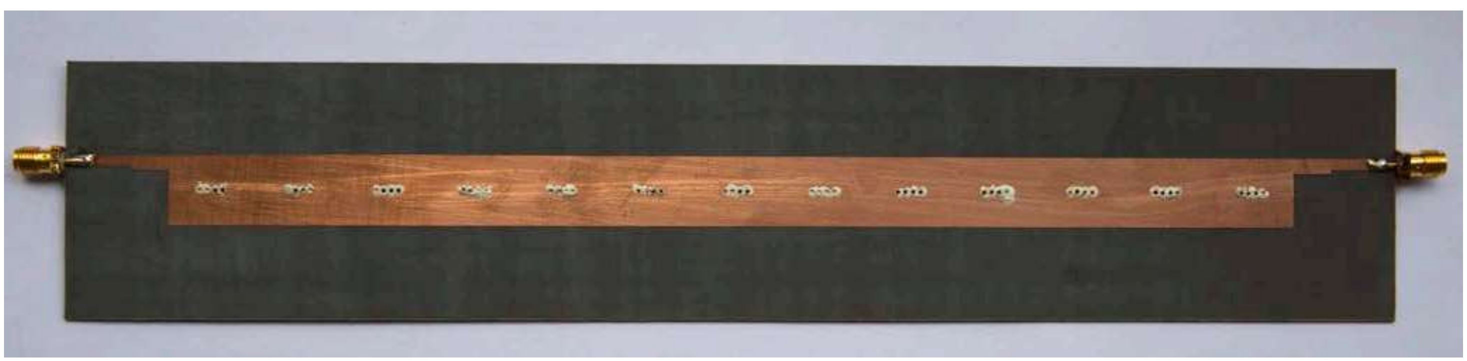
$\cos\theta_0 = \beta / k_0$
$\Delta\theta = 2\dfrac{\alpha / k_0}{\sin\theta_0}$



2. Microstrip leaky-wave antenna

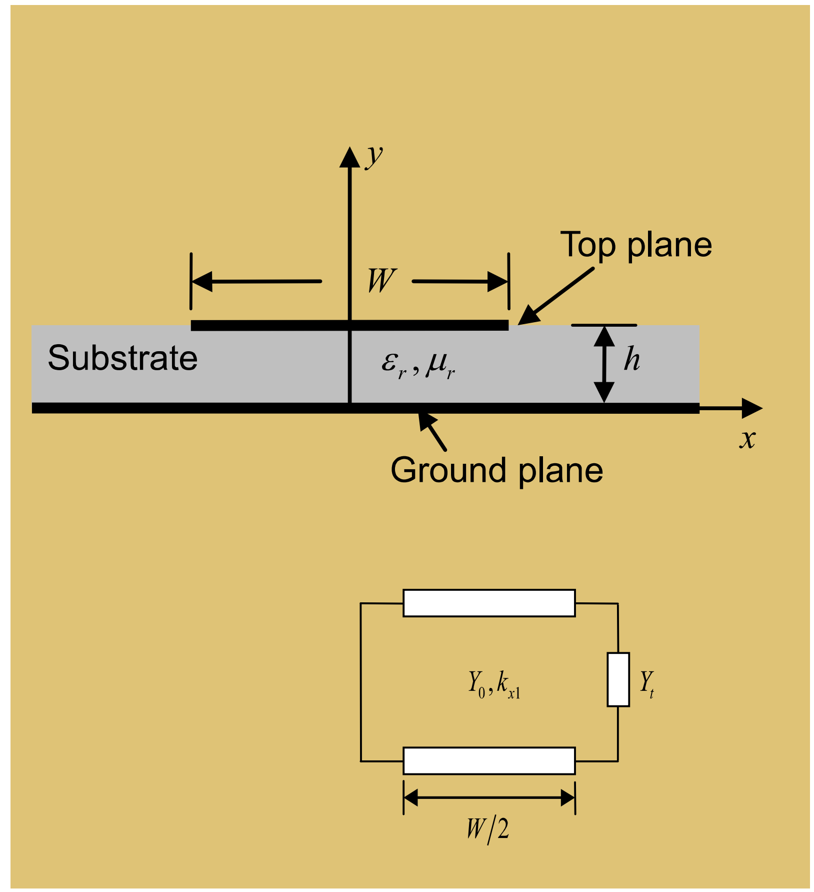
❖ Microstrip leaky-wave antenna

- Simple structure
- Usually working in the first higher mode
- Difficulty: $k_z = \beta - j\alpha$



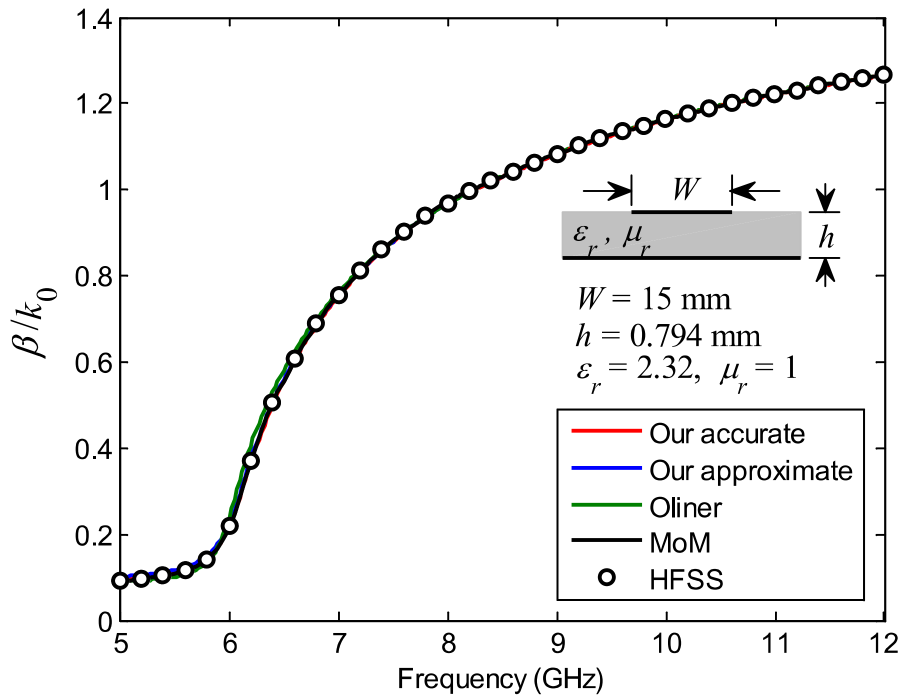
2.1. Propagation wavenumber

- Target: $k_z = \beta - j\alpha$
- Method:
  - Transverse resonant method
- Difficulties: $Y_t = Y_{t11} + Y_{t12}$
  - Self-admittance Y_{t11}
  - Mutual admittance Y_{t12}
- Methods
  - Wiener-Hopf method: Y_{t11}
  - Spectral domain method: Y_{t12}

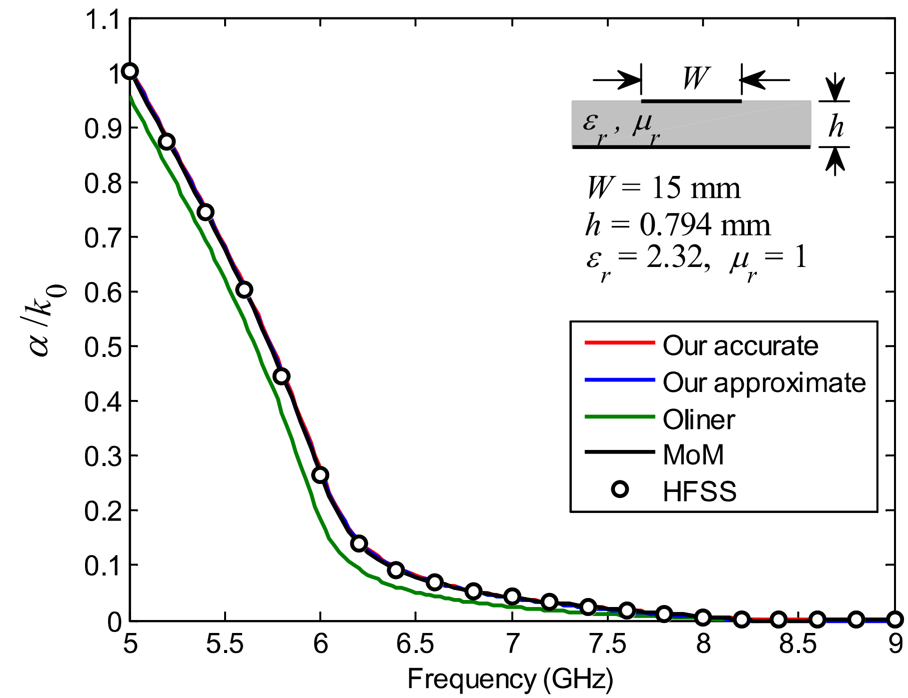


2.1. Propagation wavenumber

- Numerical results (low permittivity)



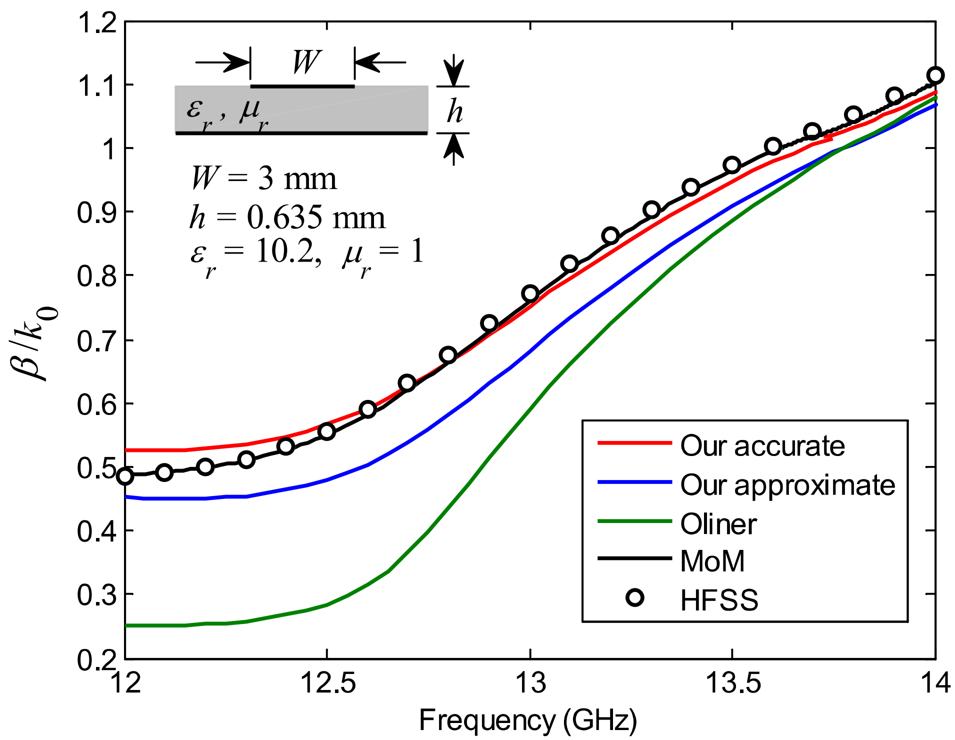
Phase constant



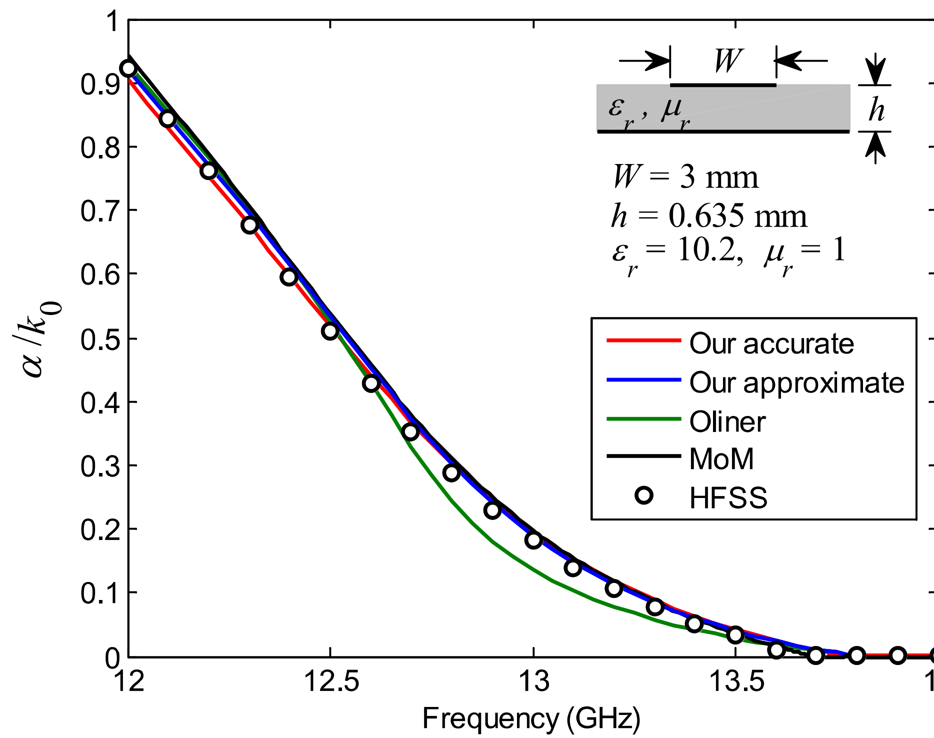
Attenuation constant

2.1. Propagation wavenumber

- Numerical results (high permittivity)



Phase constant

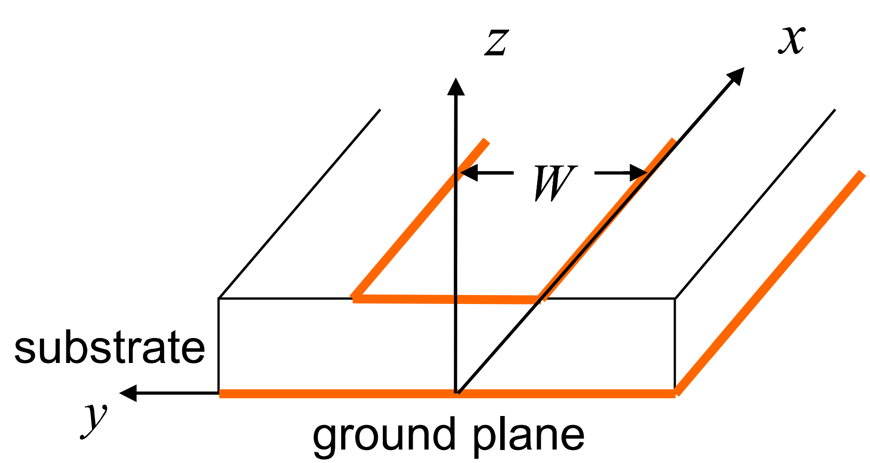


Attenuation constant

Juhua Liu*, D. R. Jackson, Yunliang Long, "Propagation wavenumbers for half- and full-width microstrip lines in the EH1 mode," IEEE Trans. Microw. Theory Tech., vol. 59, no. 12, pp. 3005–3012, Dec. 2011.

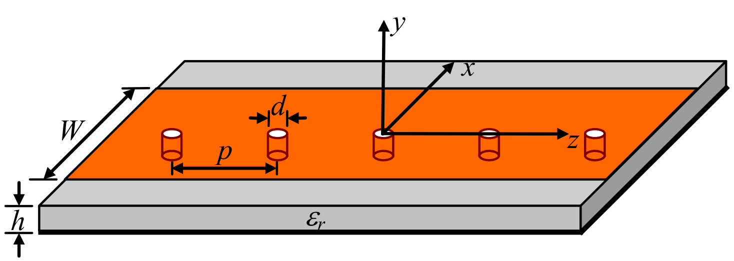
2.2. Suppression of EH_0 mode

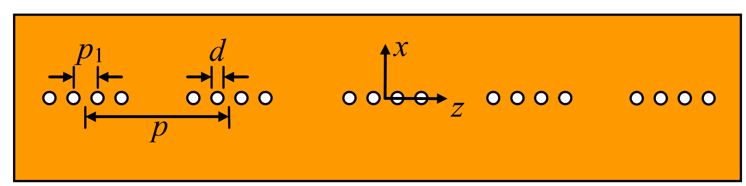
- Operating leaky mode: EH_1 mode
- Unwanted mode: EH_0 mode
  - Decreases the excitation efficiency of EH_1 mode
  - Needs to be suppressed



2.2. Suppression of EH_0 mode

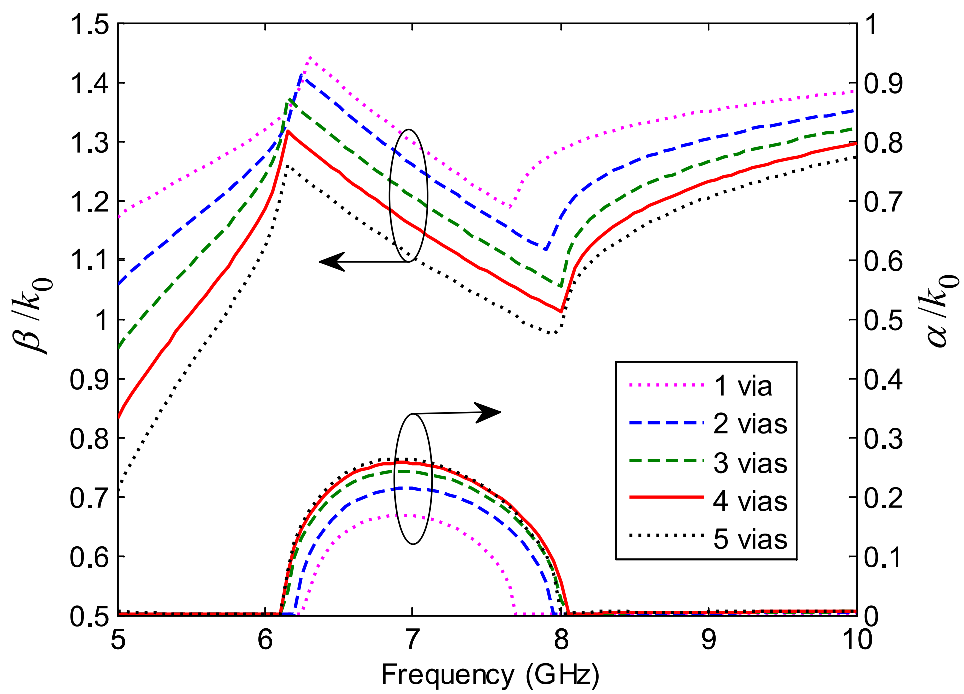
- Technique: periodic shorting vias
- Operation principles
  - Stop band generated by periodic shorting vias
  - EH_0 mode decays in the stop band, but not the EH_1 mode
  - EH_0 is effectively suppressed in the stop band



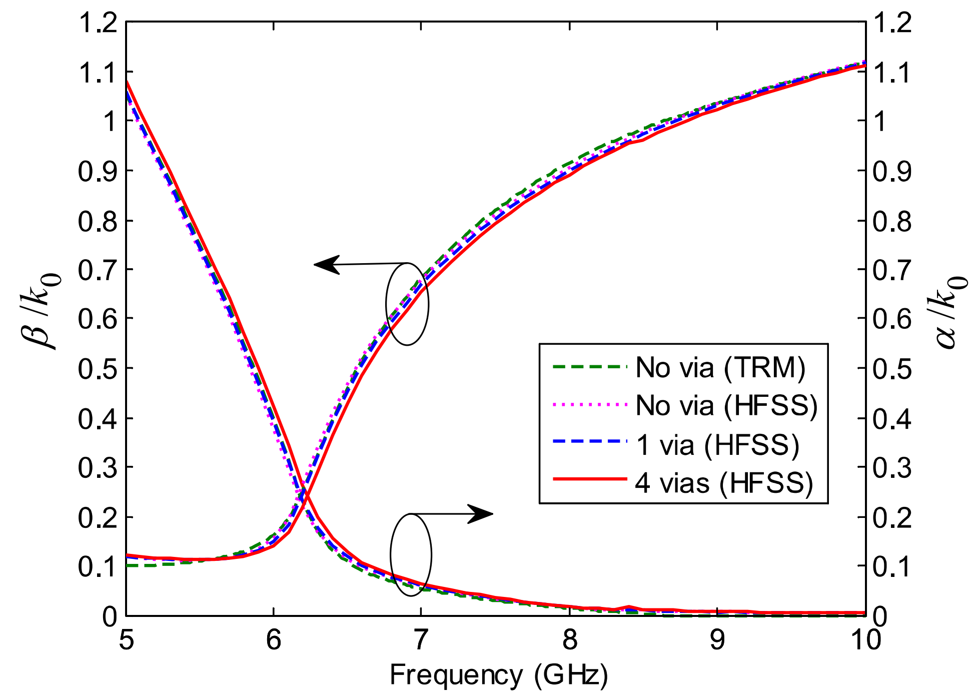


2.2. Suppression of EH_0 mode

- EH_0 stop band vs. EH_1 leaky region



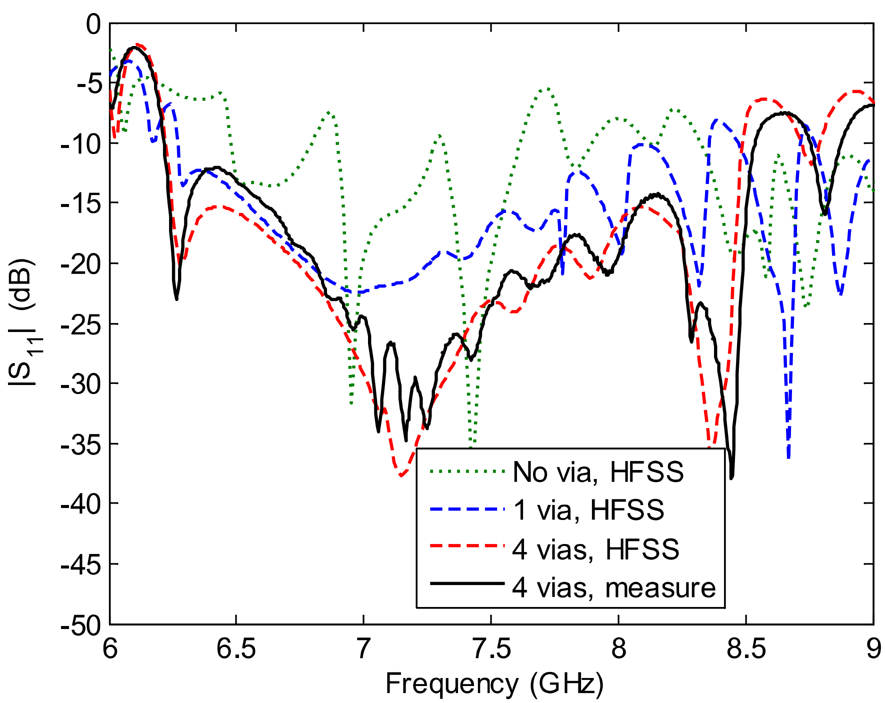
EH_0 mode

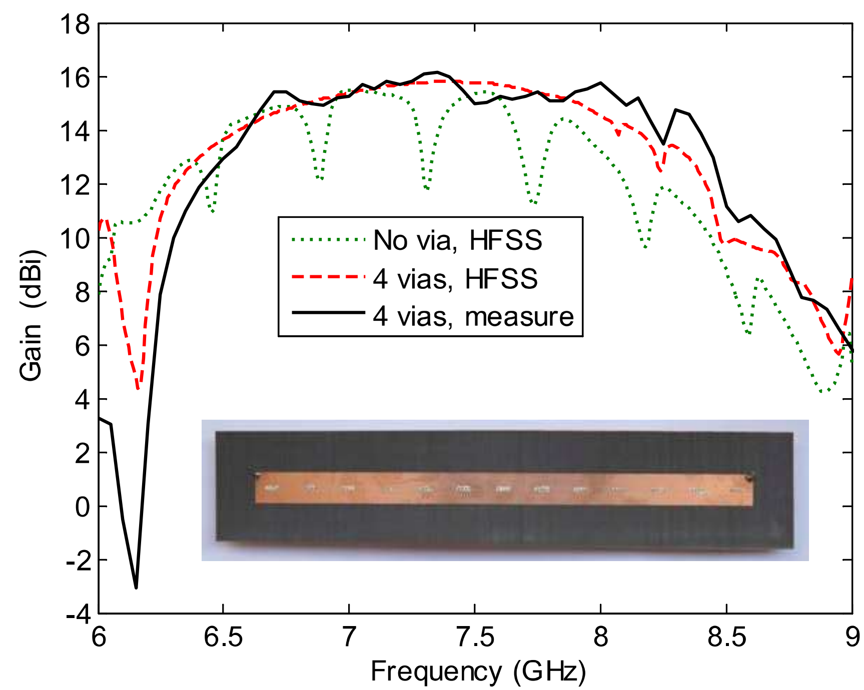


EH_1 mode

2.2. Suppression of EH_0 mode

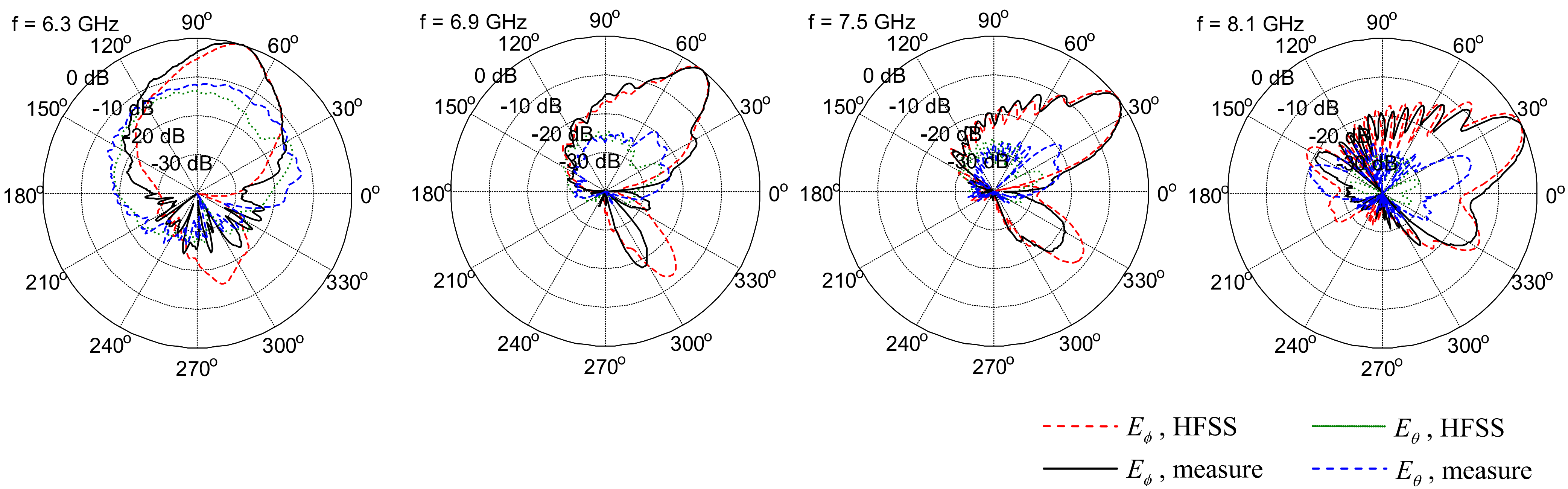
- Wider bandwidth
- Lower reflection coefficient
- More stable and higher gain





2.2. Suppression of EH_0 mode

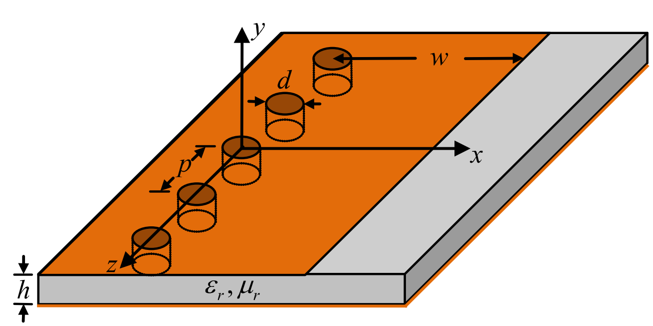
- Beam scanning with frequency



Juhua Liu*, Yuanxin Li, Yunliang Long, "Design of periodic shorting-vias for suppressing the fundamental mode in microstrip leaky-wave antennas," IEEE Transactions on Antennas and Propagation, vol. 63, no. 10, pp. 4297-4304 October 2015.

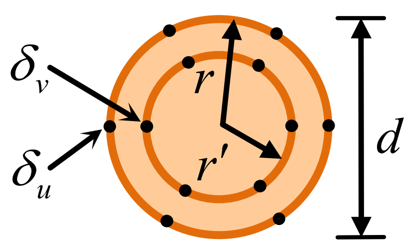
2.3. Half-Mode SIW leaky-wave antenna

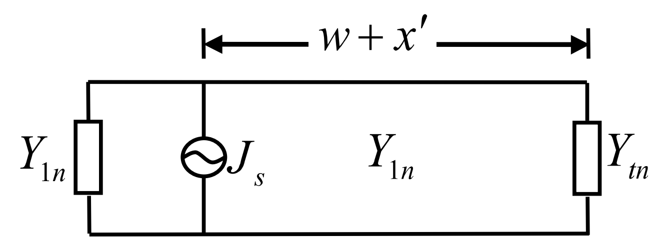
- Half-mode substrate integrated waveguide (HMSIW) leaky-wave antenna
  - Similar to half-width microstrip leaky-wave antenna
  - No need to suppress any other mode (e.g., EH_0 mode)
  - Fundamental mode: leaky mode, similar to the EH_1 mode in the a microstrip line
  - Gain: not as high as a full-width microstrip leaky-wave antenna



2.3. Half-Mode SIW leaky-wave antenna

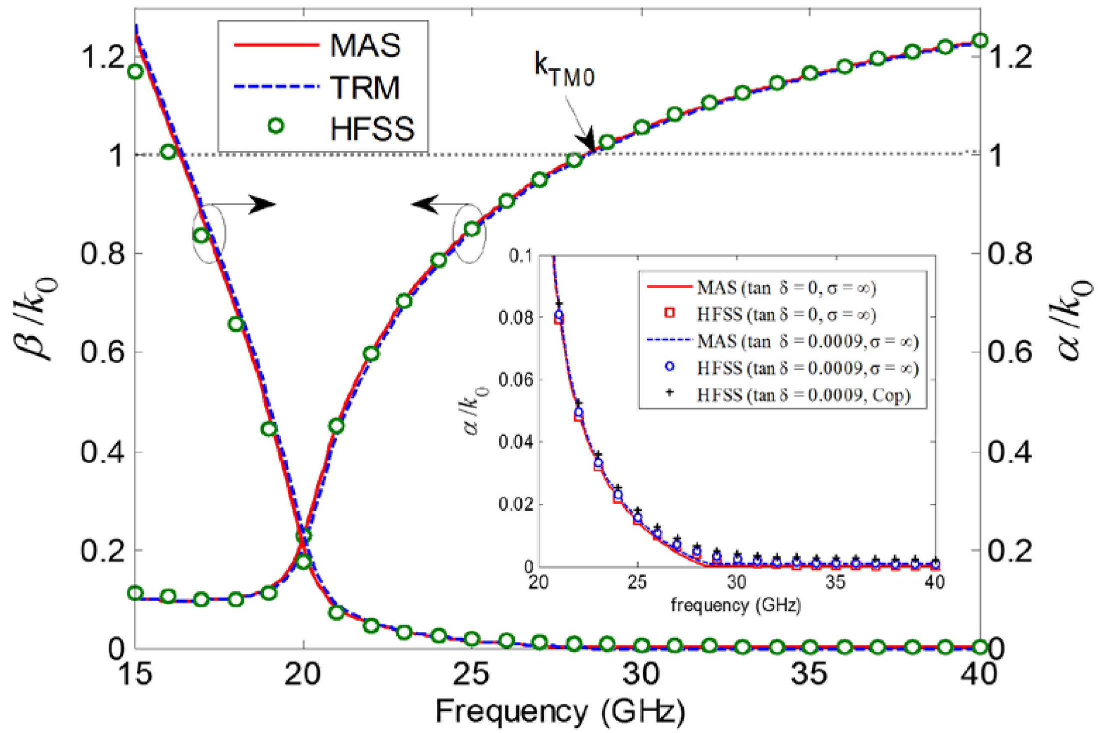
- Accurate and efficient calculation of the propagation wavenumber
- Analysis method:
  - Method of auxiliary sources (MAS)
  - Equivalent transverse network
  - Simple, accurate, efficient





2.3. Half-Mode SIW leaky-wave antenna

- Propagation wavenumber $k_z = \beta - j\alpha$



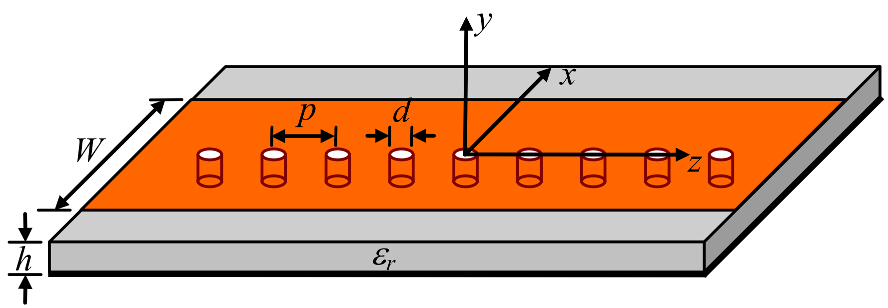
Juhua Liu*, Yuanxin Li, Shaoyong Zheng, Yunliang Long, "Method of auxiliary sources for analyzing half-mode substrate integrated waveguide," IEEE Antennas Wireless and Propagation Letters, vol. 13, pp. 1043 – 1046, 2014.

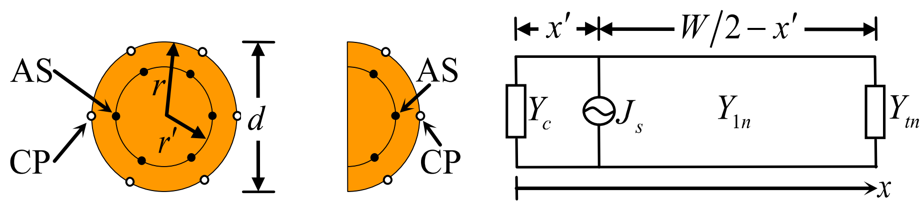
2.4. EH_0 leaky mode in via-loaded microstrip line

- EH_0 mode in non-loaded microstrip line
  - Fundamental mode
  - Slow wave, bound mode
  - Even mode
- EH_0 mode in via-loaded microstrip line
  - Fast wave
  - Leaky mode
  - Even mode

2.4. EH_0 leaky mode in via-loaded microstrip line

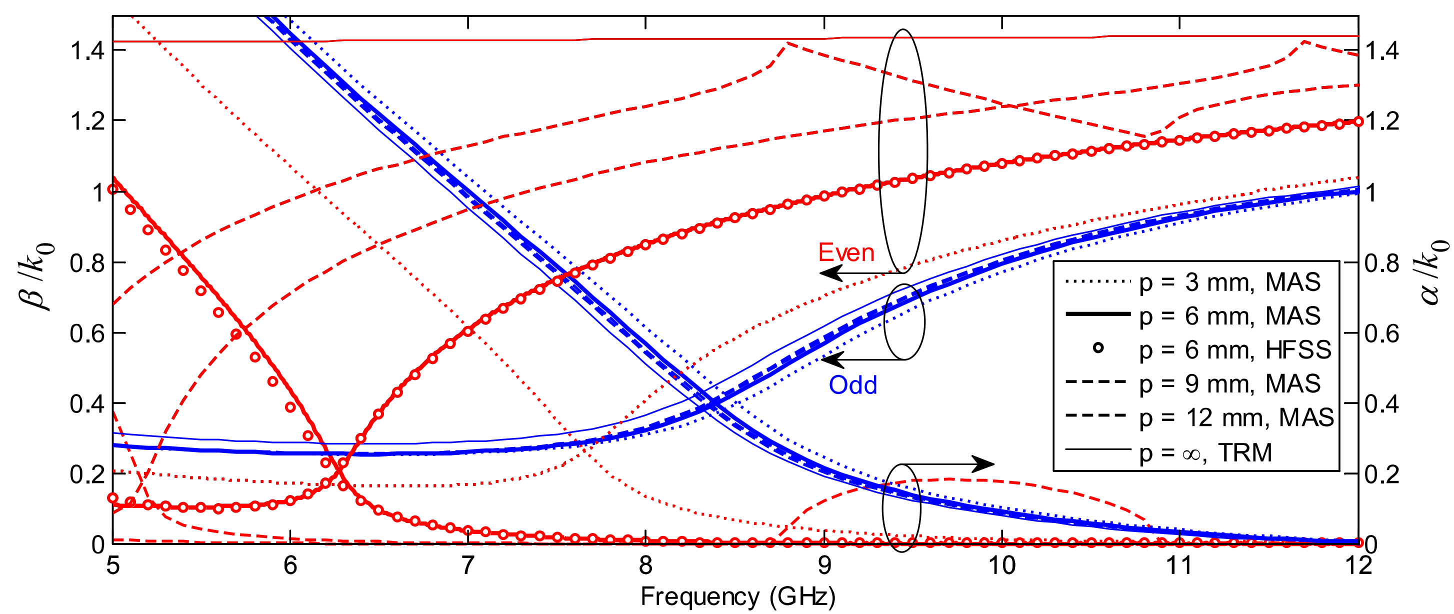
- Via-loaded microstrip line
  - Propagation wavenumber
  - Method of auxiliary sources (MAS)
  - Transverse equivalent circuit





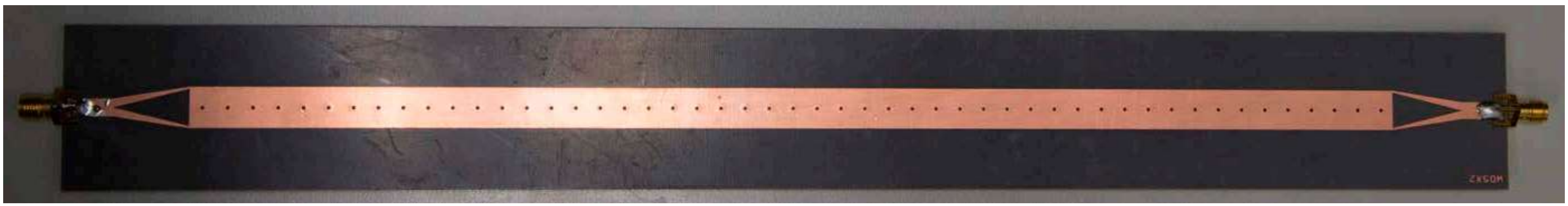
2.4. EH_0 leaky mode in via-loaded microstrip line

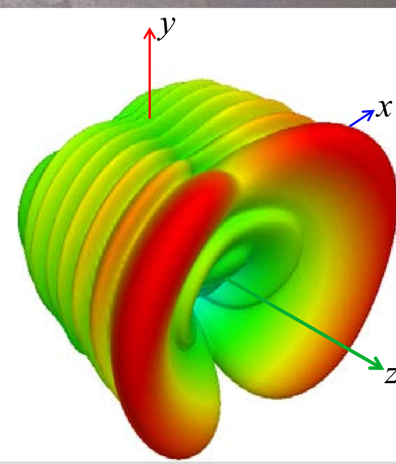
- Propagation wavenumber $k_z = \beta - j\alpha$
  - EH_0 mode: even mode
  - EH_1 mode: odd mode



2.4. EH_0 leaky mode in via-loaded microstrip line

- Microstrip EH_0-mode leaky-wave antenna



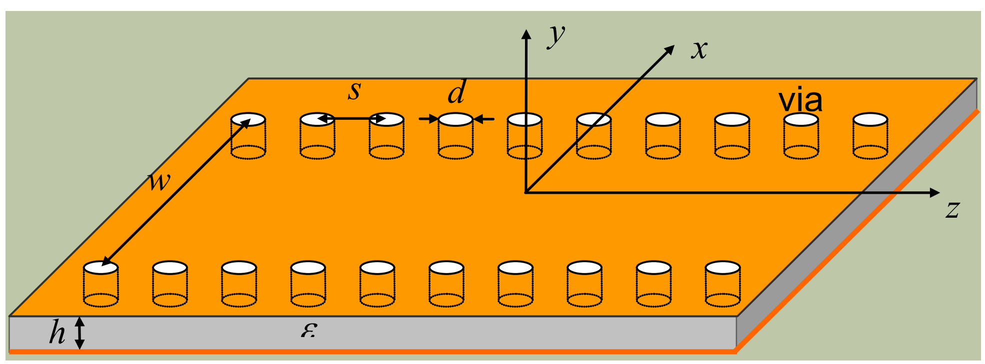


Juhua Liu*, Yuanxin Li, Yunliang Long, "Fundamental even leaky mode in microstrip line loaded with shorting vias," IET Microwaves Antennas & Propagation, vol. 11, no. 1, pp. 129-135, Jan. 2017.

3. SIW leaky-wave antennas

Substrate integrated waveguide (SIW)

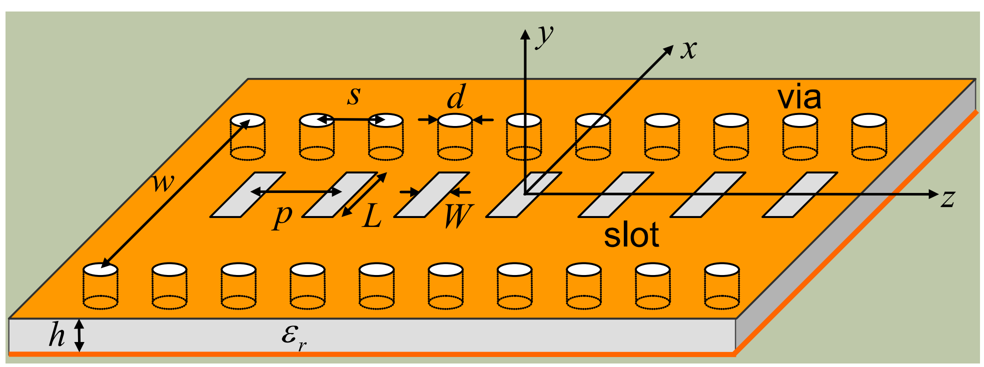
- Advantages
  - Low cost, light weight
  - Easy fabrication
  - Easy integration
- Can be approximated as rectangular waveguide



3.1. SIW leaky-wave antenna with transverse slots

❖ SIW with periodic transverse slots

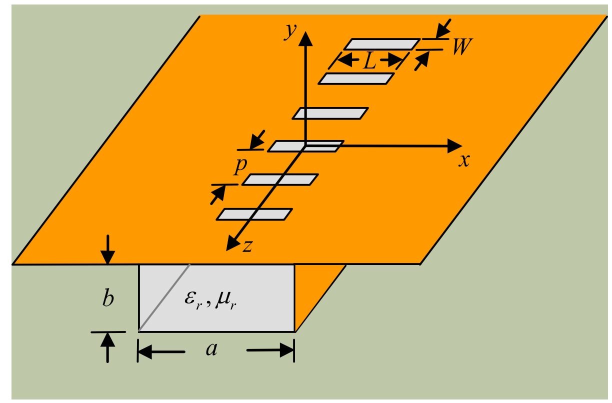
- Leaky-wave antennas: usually can not scan to endfire
- This antenna: scan to endfire
- Why? Leaky wave + surface wave
  – Leaky wave: scan from near broadside to near endfire
  – Surface wave: endfire



3.1. SIW leaky-wave antenna with transverse slots

Theoretical analysis

- SIW $\rightarrow$ rectangular waveguide
  - Magnetic field integral equation
  - Solve: $k_z = \beta - j\alpha$

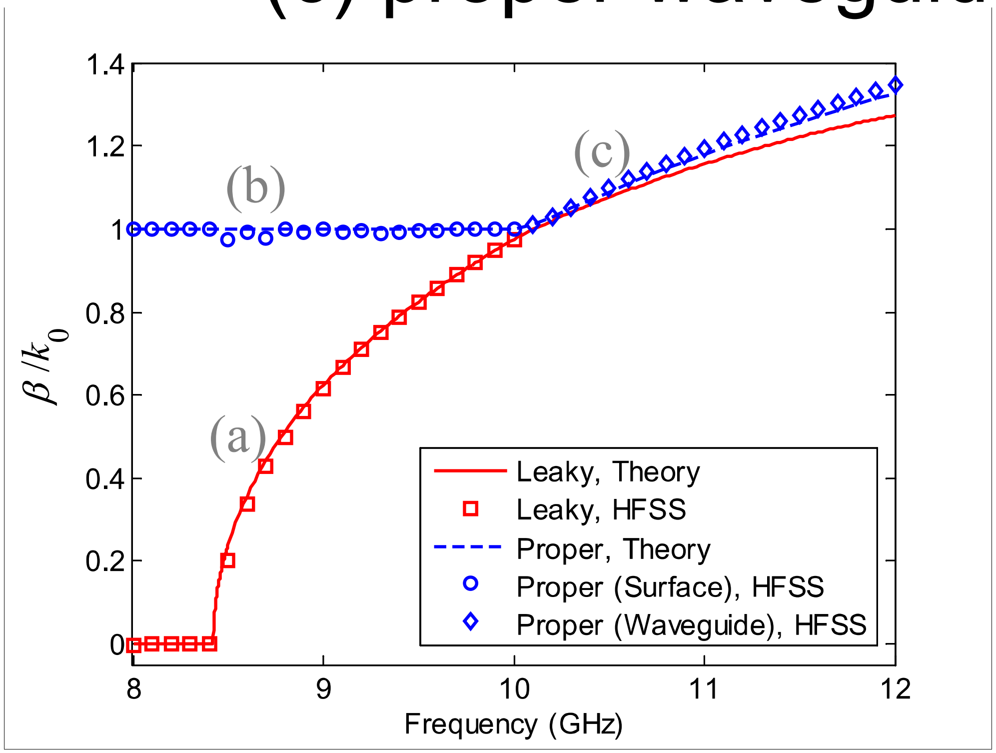


$$\sum_{n=-\infty}^{\infty} \operatorname{sinc}^2\left(k_{zn} W/2\right) \cdot \left\{ \sum_{m=1,3,5,\dots}^{\infty} \left[k_1^2 - \left(\frac{m\pi}{a}\right)^2 \right] \frac{\cos^2\left(\frac{m\pi L}{2a}\right)}{\left(1 - \frac{m^2 L^2}{a^2}\right)^2} \frac{\cot\left(k_{ymn1} b\right)}{k_{ymn1} b} + j\frac{\pi^2}{16} \cdot \frac{\mu_r a}{L^2 b} \cdot I_n \right\} = 0$$

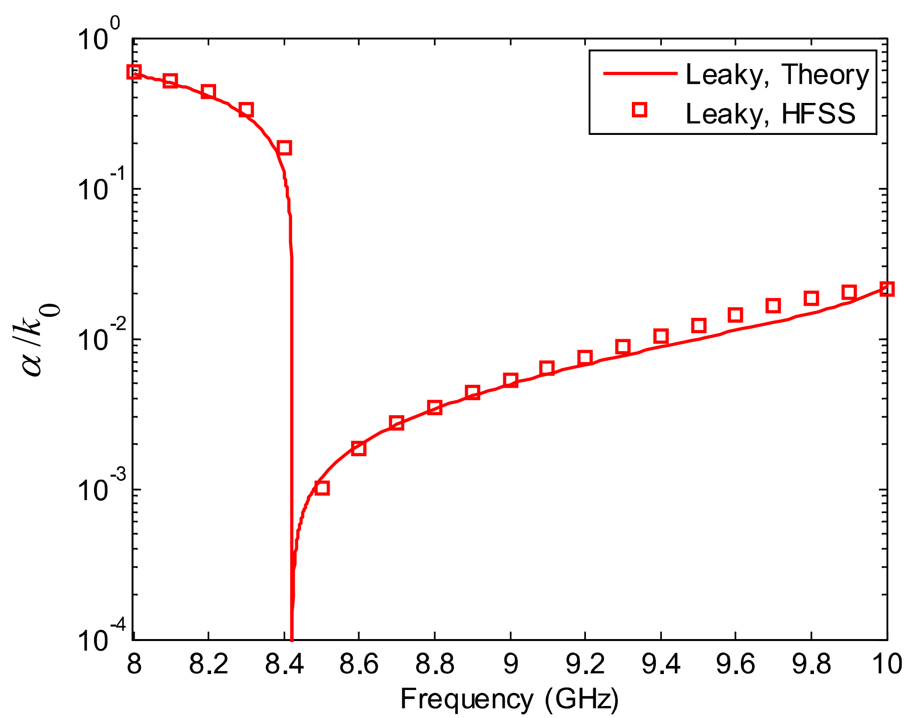
Juhua Liu*, D. R. Jackson, Yunliang Long, “Modal analysis of dielectric-filled rectangular waveguide with transverse slots,” IEEE Transactions on Antennas and Propagation, vol. 59, no. 9, pp. 3194-3203, September 2011.

3.1. SIW leaky-wave antenna with transverse slots

- Numerical results:
  - (a) Leaky mode, (b) surface-wave mode, (c) proper waveguide mode

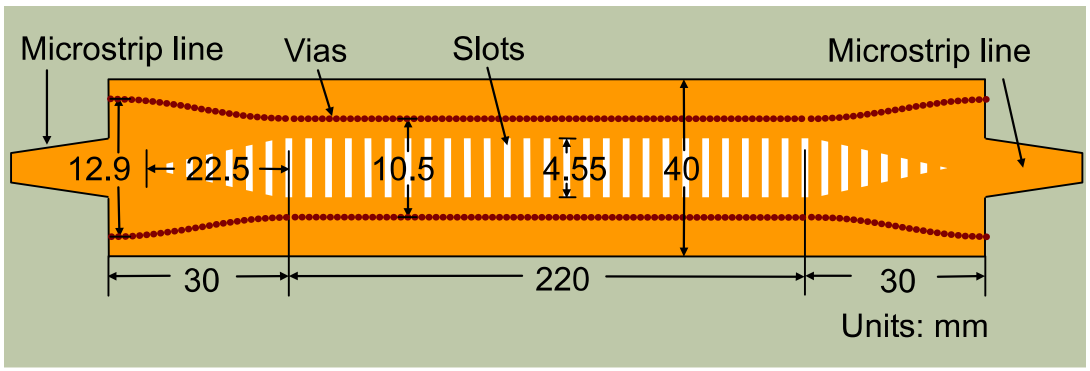


Phase constant

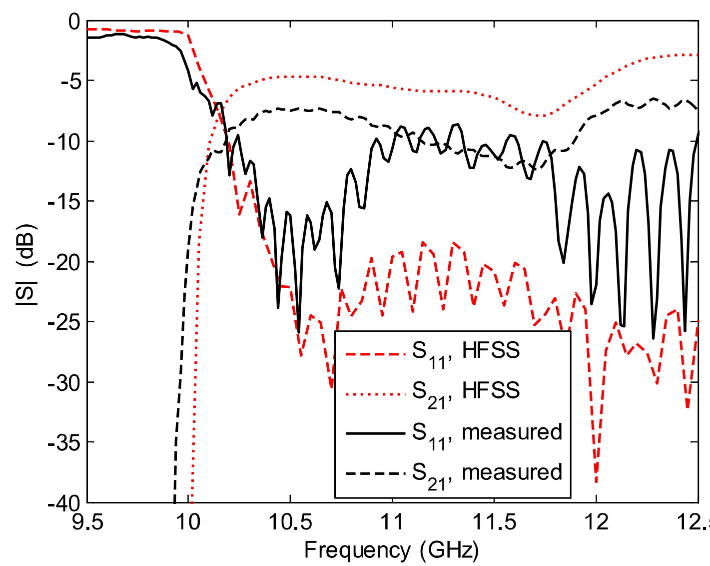


Attenuation constant

3.1. SIW leaky-wave antenna with transverse slots



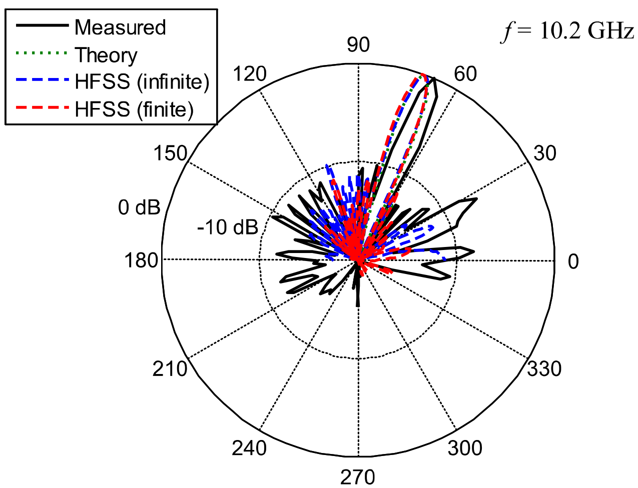
Antenna configuration

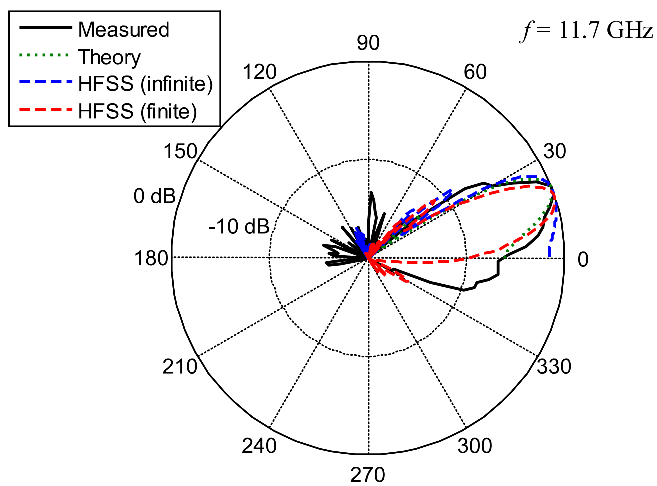


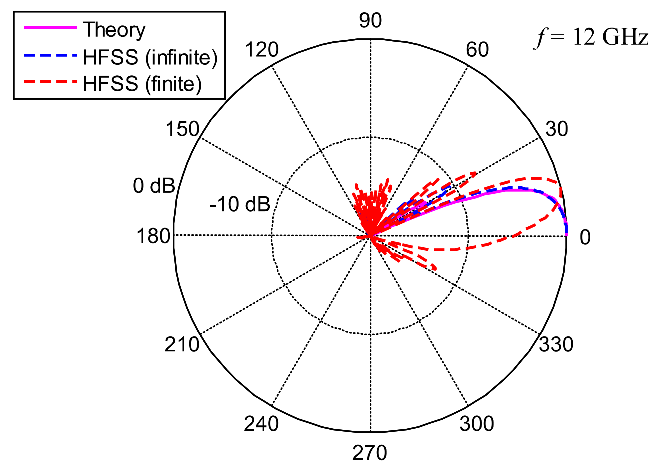
S11 & S21

3.1. SIW leaky-wave antenna with transverse slots

- Capable to scan to endfire





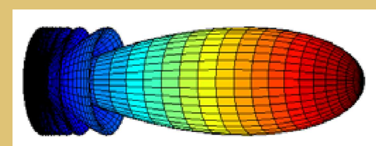


Juhua Liu*, D. R. Jackson, Yunliang Long, "Substrate integrated waveguide (SIW) leaky-wave antenna with transverse slots," IEEE Transactions on Antennas and Propagation, vol. 60, no. 1, pp. 20-29, January 2012.

3.2 Endfire radiation

- Consider: a traveling-wave antenna

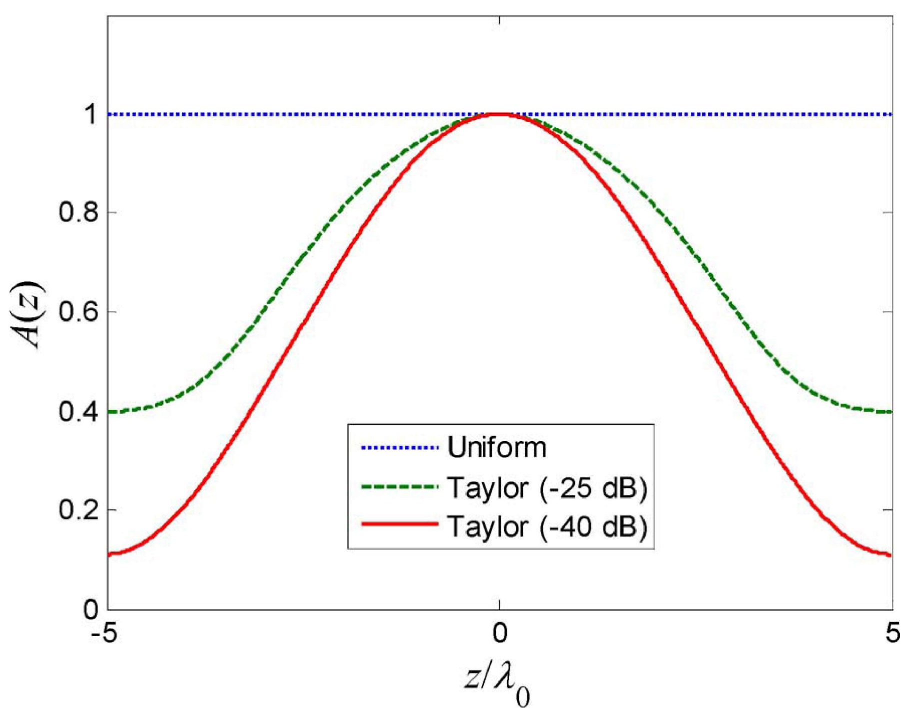
$$M(z) = A(z)e^{-j\beta z}$$



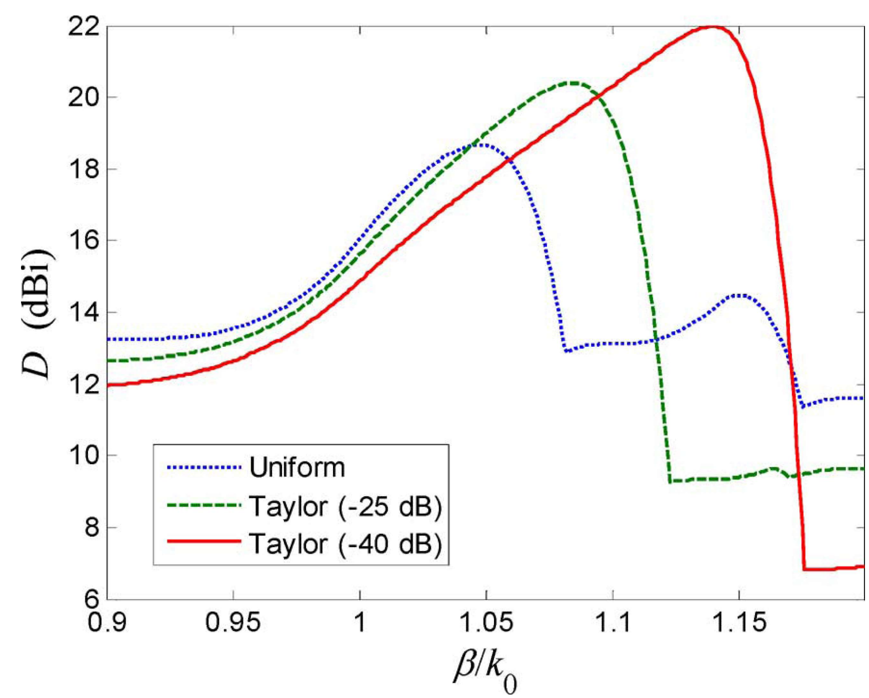
- Usually, when $\beta < k_0$, a line source with uniform $A(z)$ distribution has a higher directivity than a tapered one.
- However, when when $\beta > k_0$, we found that the rule is not correct.

3.2 Endfire radiation

- Comparison of different amplitude distributions
- When $\beta > k_0$, a tapered distribution provides a higher peak directivity than the uniform one.



Amplitude distribution

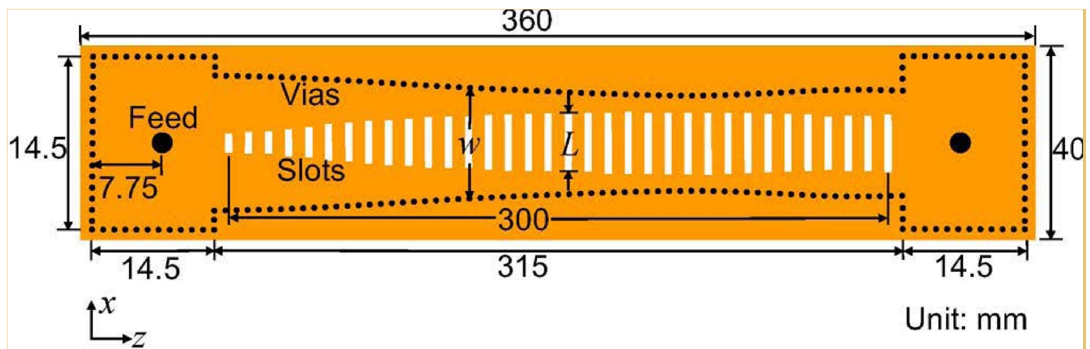


Directivity

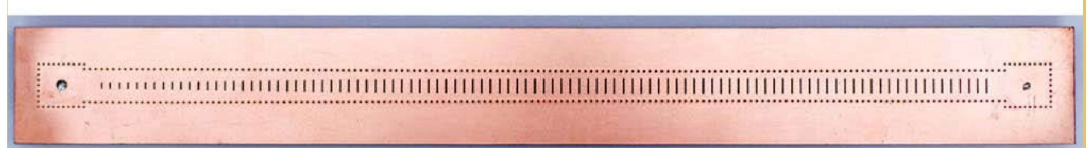
3.2 Endfire radiation

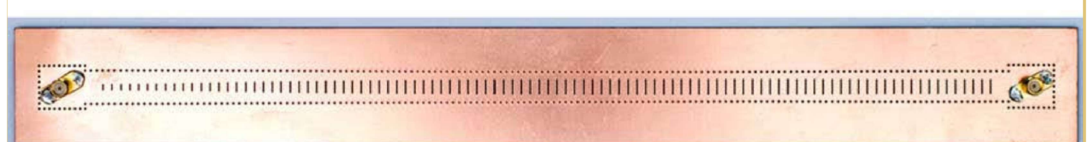
❖ SIW travelling-wave antenna with tapered slots

- Geometry
- Top view
- Bottom view



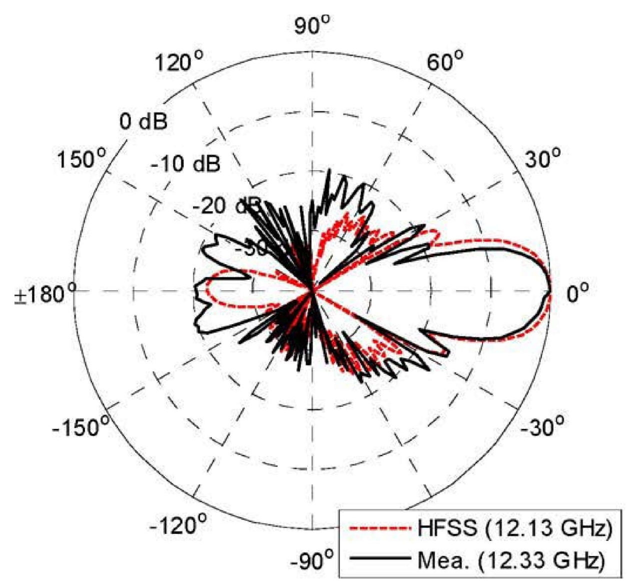
(a)

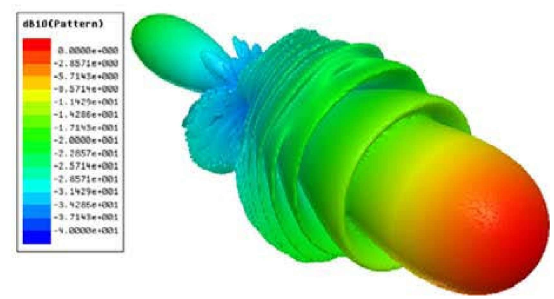

(b)


(c)

3.2 Endfire radiation

- The pattern for the tapered antenna with the highest directivity



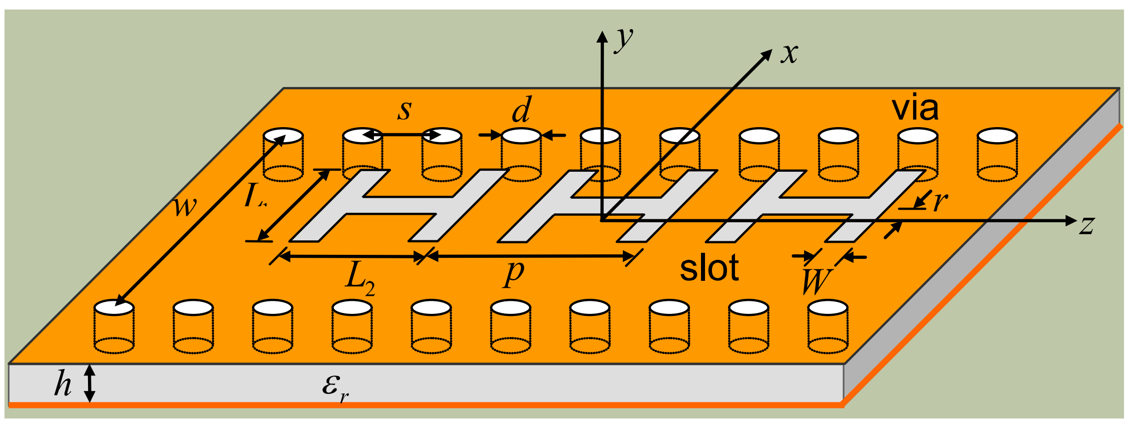


Juhua Liu*, David R. Jackson, Yuanxin Li, Chaoqun Zhang, and Yunliang Long, "Investigations of SIW leaky-wave antenna for endfire-radiation with narrow beam and sidelobe suppression," IEEE Transactions on Antennas and Propagation, vol. 62 , no. 9, pp. 4489-4497, September 2014.

3.3. SIW leaky-wave antenna with H-shaped slots

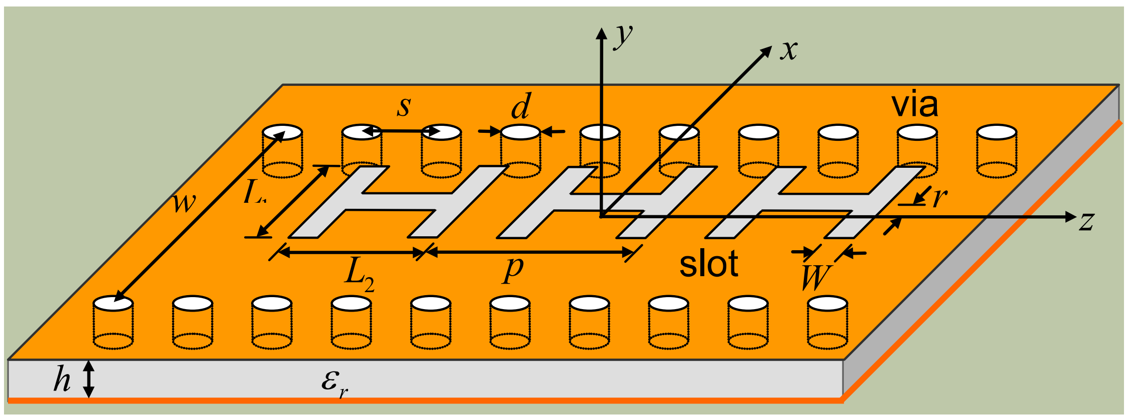
❖ SIW with H-shaped slots

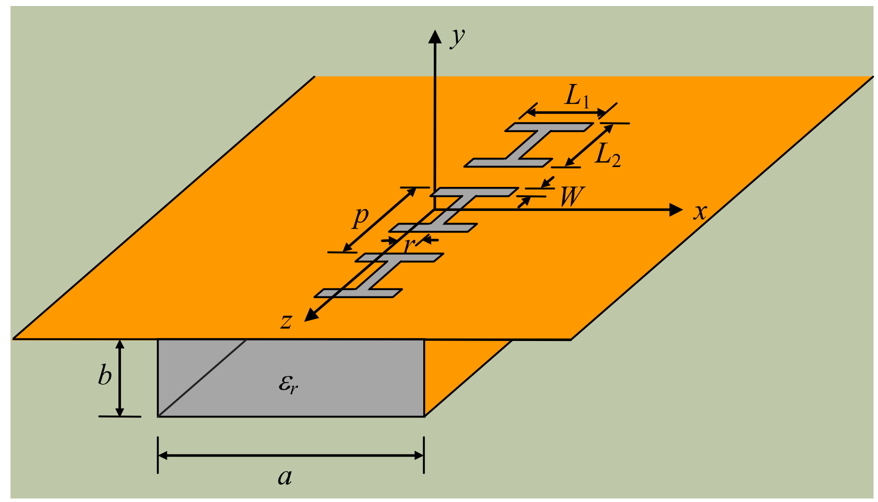
- Circular polarization
- High and flat leakage constant



3.3. SIW leaky-wave antenna with H-shaped slots

- Analysis method: magnetic field integral equation





Juhua Liu*, Yunliang Long, "A full-wave numerical approach for analyzing rectangular waveguides with periodic slots," IEEE Transactions on Antennas and Propagation, vol. 60, no. 8, pp. 3754-3762, August 2012.

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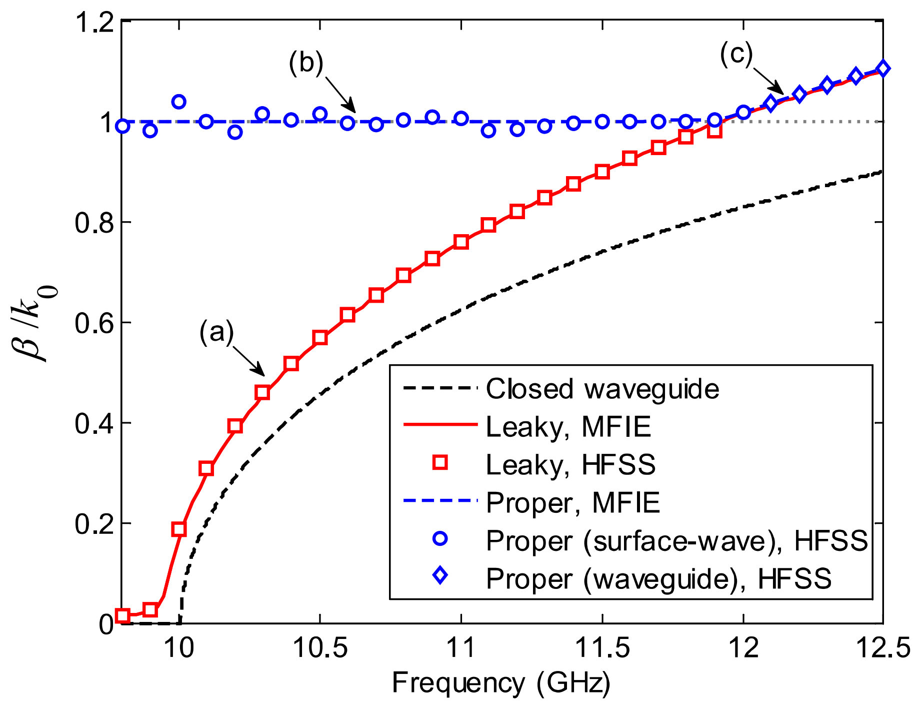
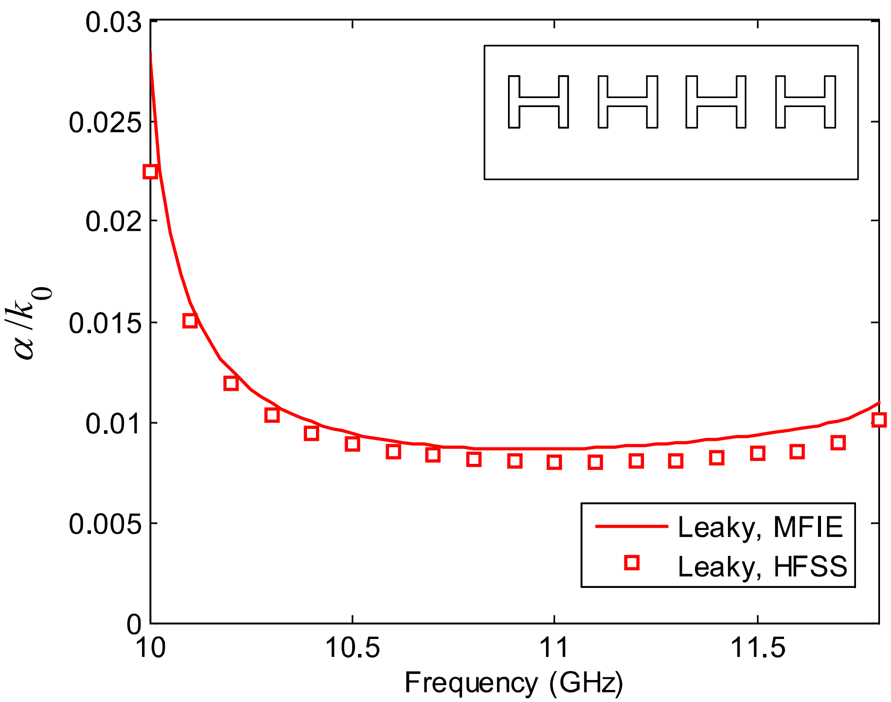
3.3. SIW leaky-wave antenna with H-shaped slots

- Modes: (a) leaky-wave mode, (b) surface-wave mode, (c) proper waveguide mode
- Leaky constant: flat, high

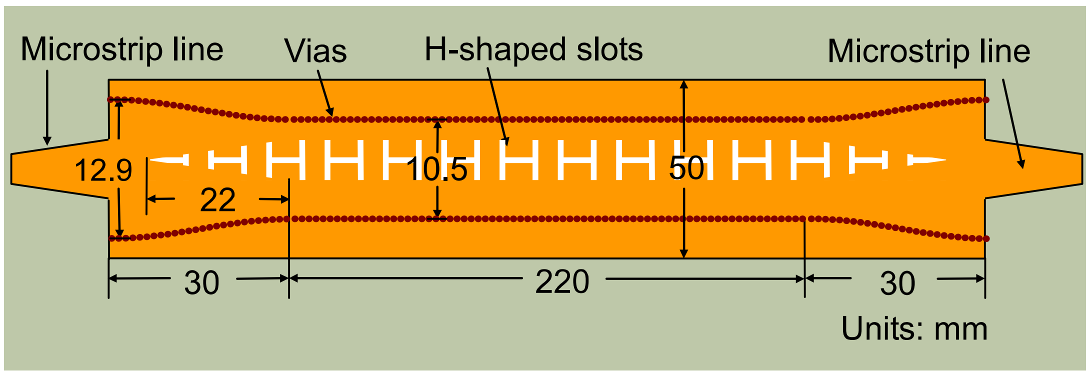


Phase constant

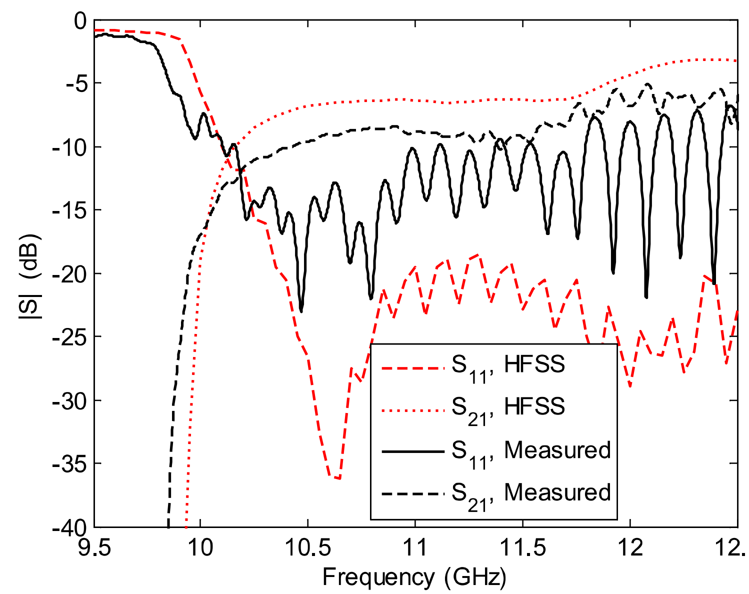


Leakage constant

3.3. SIW leaky-wave antenna with H-shaped slots



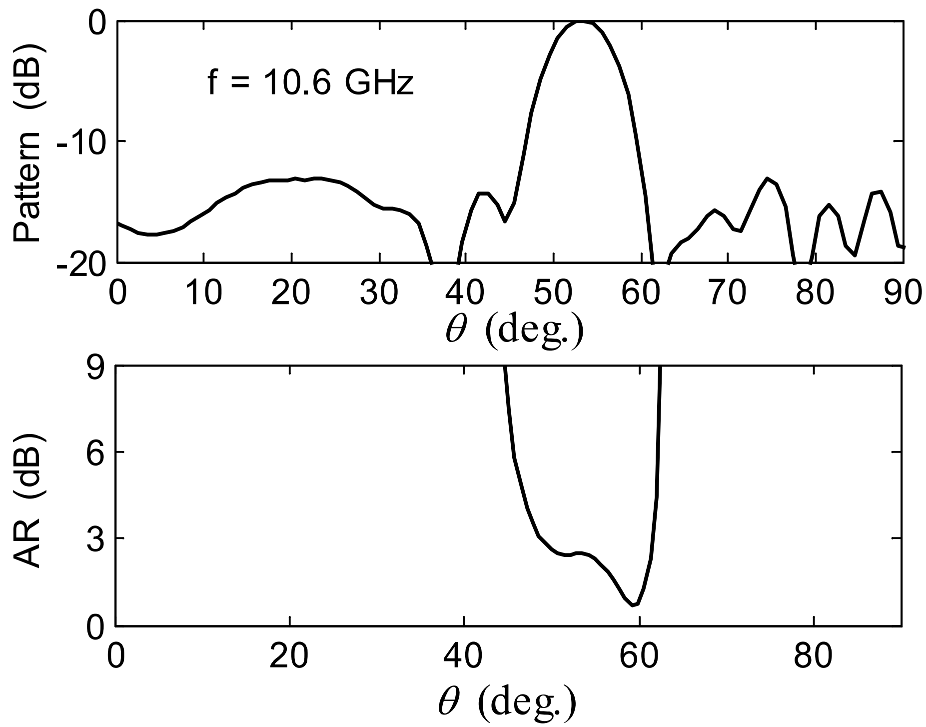
Antenna configuration



S11 & S21

3.3. SIW leaky-wave antenna with H-shaped slots

- At 10.6 GHz, circular polarization.



Juhua Liu*, Xihui Tang, Yuanxin Li, Yunliang Long, "Substrate integrated waveguide leaky-wave antenna with H-shaped slots," IEEE Transactions on Antennas and Propagation, vol. 60, no. 8, pp. 3962-3967, August 2012.

4. Conclusion

- Microstrip leaky-wave antenna
  - Calculate k_z for the EH_1 mode accurately
  - Suppress the unwanted EH_0 mode with the stop band generated by shorting vias
  - Analyze the half-mode SIW leaky-wave antenna using the method of auxiliary sources (MAS)
  - Investigate the EH_0 leaky mode in via-loaded microstrip line

- SIW leaky-wave antenna
  - SIW leaky-wave antenna with transverse slots for endfire scanning capability
  - A tapered traveling wave antenna provides higher endfire directivity than a uniform one
  - SIW leaky-wave antenna with H-shaped slots for circular polarization

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Thank you